NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3051

GUST LOADS AND OPERATING AIRSPEEDS OF ONE TYPE OF FOUR-ENGINE TRANSPORT AIRPLANE ON THREE ROUTES FROM 1949 TO 1953

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SUMMARY

About 50,000 hours of V-G data obtained from one type of four-engine civil transport airplane operated over three different commercial airline routes of the United States from 1949 to 1953 are analyzed to determine the magnitude and frequency of occurrence of gust loads and gusts. The normal-acceleration increments for each of the three operations equaled or exceeded the limit gust load factor, on the average, twice (once positive and once negative) in about 1.0×10^6 flight miles. A derived gust velocity of 50 feet per second (evaluated on the basis of NACA Technical Note 2964) was equaled or exceeded twice in about 0.5×10^6 flight miles for each of the three operations. The frequency of occurrence of the gust loads and the gusts for the present operations is in general agreement with those from similar operations of other civil transports recently investigated.

The data were examined for possible bias by maneuvers, since time-history records from other operations had indicated that the maximum positive accelerations in V-G records might be so biased, but no clearly defined effects of maneuvers could be discerned in these data.

INTRODUCTION

In order to obtain information on the magnitude and frequency of gust loads and gusts, measurements of normal accelerations and airspeeds have been obtained over a period of years in routine operations of civil transport airplanes by means of NACA V-G and VGH recorders. The V-G recorder supplies an envelope record of the maximum accelerations with respect to the airspeeds flown and the VGH recorder supplies a time-history record of accelerations, airspeeds, and altitudes. The V-G and VGH records supplement each other and the data from them can be combined to obtain a composite picture of the distribution of the gust loads and gusts for any given set of operations.

This report, which is based on the analysis of V-G data, is part of the continuing study of the gust loads, gusts, and airspeeds measured in civil transports. The normal accelerations and airspeeds measured in one type of four-engine transport airplane operated over three different airline routes of the United States from 1949 to 1953 are analyzed. The gust loads, gusts, and airspeeds measured during these operations are compared with similar data reported in references 1 to 5.

It is pertinent to note that the method used herein for evaluation of the gust velocities is the revised method presented in reference 6 and used in reference 7.

SYMBOLS

A aspect ratio, b^2/S

b wing span, ft

$\bar{c}$ mean geometric chord, ft

W gross weight, lb

S wing area, sq ft

m slope of wing lift curve per radian

g acceleration due to gravity, ft/sec^2

ρ mass density of air, slugs/cu ft

ρ_o mass density of air at sea level, slugs/cu ft

Δn normal-acceleration increment, g units

Δn_{LLF} design limit-gust-load-factor increment, g units

μ_g airplane mass ratio (see ref. 6), $\frac{2W}{m\rho\bar{c}gS}$

K_g gust factor $\left(\text{function of } \mu_g\right)$, defined in reference 6

U_{de} derived gust velocity defined in reference 6, $\frac{2W\ \Delta n}{1.47m\rho_o SV_o K_g}$, fps (1.47 is a factor for converting airspeed from miles per hour to feet per second)

K alleviation factor (function of wing loading) defined in reference 8

V	airspeed, mph
V_{max}	maximum indicated airspeed, mph
V_B	design speed for maximum gust intensity, mph (ref. 9, p. 3)
V_C	design cruising speed, mph (ref. 9, p. 3)
V_D	design diving speed, mph (ref. 9, p. 3)
V_{NE}	never-exceed speed, mph (ref. 9, p. 36)
V_o	indicated airspeed at which maximum positive or negative acceleration increment occurs on a V-G record, mph
V_p	most probable operating speed at which maximum acceleration increment occurs in a sample of V-G data, mph
C_N	normal-force coefficient
N	total number of observations in a sample of data
T	total flight time for number of V-G records in a sample, hr
τ	average flight time per V-G record, hr
P	probability that maximum value on a V-G record will equal or exceed a given value
u	location parameter of distribution of extreme values (ref. 10, p. 2
α	scale parameter of distribution of extreme values (ref. 10, p. 2)
σ_V,σ_o	standard deviations of distributions of V_{max} and V_o, respectivel (ref. 11, p. 73)
k_V,k_o	coefficients of skewness of distributions of V_{max} and V_o, respectively (ref. 11, p. 73)

Subscripts:

max	maximum value of the variable
50	value of 50 feet per second for the derived gust velocity

A bar over a symbol indicates the mean value of the variable for a given set of observations.

APPARATUS AND SCOPE OF DATA

The data were obtained with two types of NACA V-G recorders; the friction-damped recorder and the oil-damped recorder which differ mainly in the method of damping the accelerometer elements (see ref. 12). A total of 11 civil transport airplanes were instrumented with V-G recorders (see table I) for collecting data during normal airline operations. In all cases, the recorders were installed close to the center of gravity of the airplanes. The airplane characteristics used for evaluating the data are:

Design gross weight, W, lb	89,900
Wing area, S, sq ft	1,463
Wing span, b, ft	117.5
Mean geometric chord, $\bar{c}$, ft	13.7
Aspect ratio, A	9.4
Maximum normal-force coefficient, $C_{N_{max}}$	1.6
Limit-gust-load-factor increment (computed), g units	1.43
Gust-alleviation factor, K (see ref. 8)	1.218
Slope of lift curve per radian $\left(\text{computed from } \dfrac{6A}{A + 2}\right)$	4.95
Mass ratio, μ_g, (see ref. 6) for 85 percent gross weight at 10,000 ft	27.3
Gust factor, K_g, (see ref. 6) for 85 percent gross weight at 10,000 ft	0.745
Design speed for maximum gust intensity, V_B, mph (see ref. 9)	183
Design cruising speed, V_C, mph (see ref. 9)	279
Design diving speed, V_D, mph (see ref. 9)	388
Never-exceed speed, V_{NE}, mph (see ref. 9)	349

These values were obtained from the manufacturer's design data and the operating manual or were computed, as indicated in the table. The limit-gust-load-factor increment of 1.43g was computed according to the formula given in the Civil Air Regulations design specifications (see ref. 9) by using an effective gust velocity of 30 feet per second at V_C, a value of K based on gross weight, and the value of the computed slope of the lift curve. The values given for μ_g and K_g were calculated as indicated in appendix A.

The scope of the V-G data collected in the period from 1949 to 1953 is summarized in table I for the three different operations designated herein as A, B, and C. Two hundred and twenty-six V-G records, representing a total of about 50,000 flight hours, were collected from 11 airplanes of the three operations. As table I shows, one portion of the records from operation A was collected on a transcontinental route from New York to Los Angeles and the other portion was obtained on a transoceanic route from the west coast of the United States to Hawaii. The records of operation B were collected essentially on land routes in the southern and eastern sections of the United States although some flights may have been made to San Francisco because of an airplane interchange arrangement. The records of operation C were collected on routes in the Caribbean region.

EVALUATION OF RECORDS AND ANALYSIS

Figure 1 illustrates a V-G record and indicates the values that were read. Routine details of the method of evaluation used are given in appendix A and the analytical procedures applied to the present data are outlined in appendix B.

The main differences between the present analysis and past analyses of similar data are:

(a) Examination of time-history records (VGH) collected during normal airline operations has indicated that maneuvers may bias the positive accelerations; therefore, the positive and the negative accelerations are given as separate tabulations herein for the purpose of studying this phase of the problem.

(b) The gust-velocity data presented were derived by using a method of calculation proposed in reference 6 (refer to appendix A for details). The revised formula includes a new gust factor based on mass ratio instead of wing loading and also a new gust profile represented by a one-minus-cosine curve. The effect of operating altitude is accounted for in the revised formula. The gust velocities derived in the present investigation according to this formula are larger by a factor of roughly 1.6 than those computed by use of the "effective" gust velocity formula given in the list of symbols of reference 8.

Although it is recognized that the dynamic response of the aircraft structure may significantly influence the accelerations measured at the center of gravity, the dynamic-response effect is not known or accounted for in the present gust-load and gust results. Comparisons between the results of operations A, B, and C are not influenced by this effect since only one type of airplane is involved. Dynamic-response effects amounting to as much as 30 percent have been observed in accelerations measured in other types of transport airplanes operated in turbulent air and, since results from other types are compared with the present results, the possibility that dynamic response may be an important factor in these comparisons should not be overlooked.

Inasmuch as the present data are compared with data from other civil-transport operations which used an operating distance of 10^7 flight miles as an arbitrary operational lifetime, comparisons are made herein on the same basis only to be consistent and not to imply that this distance represents the operational lifetime of any airplane.

PRECISION AND STATISTICAL RELIABILITY

Instrumental errors.- The errors inherent in the V-G recorder do not exceed a maximum value of $\pm 0.2g$ or 3 percent of the maximum airspeed range. Errors between instruments should be random because of the number of instruments used (22 in operation A, 8 in operation B, 10 in operation C) and should average out in the analysis.

Evaluation errors.- Errors in reading the records may have occurred during the evaluation but are believed to be random and to balance out.

Statistical reliability.- An important problem in the study of the frequency of exceeding the larger gust loads, gusts, and airspeeds is to determine whether the observed or estimated differences between samples are statistically significant. Although no completely satisfactory test for this purpose has been found, reference 10 cites a method developed for measuring the reliability of sample estimates which is applicable to the present data. The method applied to the present data has given the range within which, for a given probability level (a probability level of 95 percent is used herein), the true value can be expected to lie. On this basis, estimates of the values of the average flight miles required to equal or exceed Δn_{LLF} and $U_{de_{50}}$ (as shown in figs. 2 and 3, respectively) should be reliable to within a range from 2.5:1 to 4:1.

The reliability estimates change for data taken under different operating conditions, such as when data from different airplanes operated during different periods are compared, because extraneous factors (dynamic-response effects for example) are present. For data of this character, a 5:1 ratio of frequencies has been used in past investigations as an engineering measure. In the present data, therefore, any differences which appear between the estimated values of Δn_{LLF}, and likewise $U_{de_{50}}$, (see table II) are considered significant if the values differ by more than a factor of 5:1.

No adequate method is available for easily determining the statistical reliability of the estimates of maximum airspeeds. The curve for operation A in figure 4 had to be extrapolated beyond the limits of the observed data to estimate the frequency of exceeding V_{NE}. The extrapolated portion of this curve is limited and is justified, provided that the estimate at V_{NE} is used only as an indication of the order of magnitude.

DISCUSSION

The results of this investigation are presented in the form of tables and figures. The curves shown in figures 2 and 3 were calculated on the basis of the theory of extreme values as discussed in appendix B.

Accelerations experienced.- A comparison of the incremental accelerations experienced in the present type of airplane during operations A, B, and C (see fig. 2 and table II) indicates that the limit-gust-load-factor increment Δn_{LLF} was equaled or exceeded, on the average, twice (once positive and once negative) within the range of 0.9×10^6 to 1.4×10^6 flight miles. Although the routes and operators differed, these results agree in that the acceleration increments experienced in these three operations are not significantly different at Δn_{LLF} or at the 10^7 flight miles level.

With regard to a comparison of the present results and the acceleration increments experienced in recent operations of other civil transports, table II shows no significant differences among the results at Δn_{LLF} except in one case (see ref. 4) which is borderline. The rather good agreement indicated for all the operations may be due in part to the fact that differences in airplane type, dynamic-response effect, route, and operating speeds may have tended to be compensatory.

Gusts encountered.- An examination of figure 3 indicates that, for the three operations shown, a gust velocity $U_{de_{50}}$ was equaled or exceeded twice within the range of about 0.4×10^6 to 0.7×10^6 flight miles. None of these gust values differs significantly from the others and therefore the gusts encountered by this type of airplane were about the same.

A comparison (table II) of the values of the number of flight miles required to exceed $U_{de_{50}}$ for this airplane with the values for recent operations of other civil transports shows that none of the results differs significantly from the others. Since the gusts are approximately the same for all the operations compared, it is concluded that the gusts encountered during these operations were largely independent of route, airplane, and operator.

Operating airspeeds.- An examination of operating speeds given in table II indicates that the average speed (connoted by V_p/V_C at Δn_{max}) for operation A was about 12 percent lower than those shown for operations B and C. This lower speed for operation A is not reflected, as previously noted, in any appreciable decrease in the level of the acceleration increments experienced. The magnitude of the accelerations experienced in routine airline operations is principally a function of the weight and operating speed at the time the gust is encountered, and insofar as the accelerations are concerned a decrease in the operating weight will compensate for a decrease in the operating speed. It appears likely, therefore, that in view of the fact that the accelerations experienced were about the same in the three cases the lower operating speed for operation A may have been compensated for by smaller average operating weights as compared with those of operations B and C.

Inspection of figure 4 and table II indicates that the never-exceed speed was equaled or exceeded once in about 20×10^6 flight miles for operation A and once in less than 0.5×10^6 flight miles for operations B and C. The lower probability of exceeding the never-exceed speed for operation A than those for operations B and C corresponds with a similar observation noted of the more conservative operating speed in rough air for operation A than those for operations B and C.

Seasonal effects.- The results of a study of the effects of seasonal weather changes on the gust loads and gusts are summarized as follows:

Operation	Values at 10^7 flight miles				Average operating speed V_p at Δn_{max}, mph	
	Δn_{max}		U_{de}, fps			
	Summer	Winter	Summer	Winter	Summer	Winter
A	1.72	2.00	69.0	75.7	192	187
B	1.95	1.76	77.0	72.0	209	214
C	1.80	1.83	77.0	72.2	216	208

As this table indicates, seasonal weather changes accounted for the fact that the acceleration increments experienced in operation A were 14 percent smaller in summer (April through September) than in winter (October through March). These results agree with those given in reference 3 which shows 10-percent-smaller gust loads in summer than in winter for a comparable route across the northern United States. The accelerations experienced in operation B, on the other hand, were 10 percent larger in summer than in winter. This result agrees with those given in reference 5 which indicates that more severe turbulence was encountered in summer than in winter on comparable southern and eastern United States routes. The accelerations experienced in operation C and those from the data of reference 4 for Caribbean and South American operations indicate essentially no difference between summer and winter operations

Gust-load envelopes.- An examination of figures 5 to 7 indicates that the envelope calculated for each of the three operations presented agrees well with its respective composite V-G record.

As previously pointed out, there has been reason to believe that the maximum positive accelerations in V-G records might be biased by maneuvers. The data were studied for such bias but, as figures 5 to 7 tend to show, no clear-cut indications have been found with respect to the influence of maneuvers. The possibility of such bias should not be overlooked, however, in future analyses of V-G records.

Inspection of figure 8 indicates that the design gust-load diagram, prepared according to the gust-load requirements of reference 9, may be exceeded by an appreciable amount within the operating-speed range from V_B to V_C in a distance of 10^7 flight miles for each operation. These airplanes have operated such a small part of the total flight time in the speed range from V_C to V_D that they have not encountered any large gusts in this range. It should be noted that the design diagram in this case has been derived for gross weight and is not strictly comparable with these flight envelopes which more nearly approximate an 85-percent-gross-weight flight condition. If the weight difference between the flight envelopes and the design diagram were corrected for, the agreement would be closer between flight and design over the range from V_B to V_C and a considerable margin of safety would be apparent in the range from V_C to V_D.

Comparison of gust-velocity envelopes.- The gust-velocity envelopes derived for operations A, B, and C are compared in figure 9 with the overall range in similar envelopes calculated from the data on which references 1 to 5 are based, although a lack of knowledge of certain factors which influence these comparisons is recognized. The differences in weights and operating altitudes in turbulence and dynamic-response effects are factors which are not corrected for in these results. Speed differences between types of airplanes are accounted for, however, by plotting the airspeeds according to the relation V/V_C.

Figure 9 indicates reasonably good agreement between the gust-velocity envelopes for operations A, B, and C and the envelope boundary representing the range for United States civil transports in operations from 1937 to 1950. The gust-velocity envelope for operation A is within a design gust diagram, prepared according to the gust requirements of reference 13, over the whole speed range. Operations B and C exceed the design diagram over the operating speed range from about $0.6V/V_C$ to $0.85V/V_C$. The gust-velocity envelopes derived for 10^7 flight miles in each of the three operations analyzed are in general agreement, within the speed range used most of the time, with a design diagram for this type of airplane, despite the fact that route, operating conditions, and data samples differed in these operations.

SUMMARY OF RESULTS

The results of an analysis of V-G data obtained from one type of four-engine transport airplane operated on three airline routes from 1949 to 1953 are in general agreement with those from similar investigations on other civil transports. This report makes use of the recently presented method of NACA Technical Note 2964 for evaluating the gust velocities in terms of the "derived" gust velocity U_{de}. For this type of airplane and altitudes flown, U_{de} is roughly 1.6 times the formerly used "effective" gust velocity U_e. Specific results indicated are:

1. The acceleration increments equaled or exceeded the limit-gust-load-factor increment Δn_{LLF}, on the average, twice in about 1.0×10^6 flight miles.

2. A derived gust velocity of 50 feet per second was encountered, on the average, twice in about 0.5×10^6 flight miles.

3. The never-exceed speed was equaled or exceeded once in about 20×10^6 flight miles in one operation and once in about 0.5×10^6 flight miles in each of the other two operations.

4. Seasonal weather changes accounted for the fact that the accelerations experienced were 14 percent smaller in summer operations than in winter on a northern transcontinental and transpacific route, and 10 percent larger in summer operations than in winter on southern and eastern United States routes. The accelerations experienced were about the same in summer and winter for Caribbean – South American operations.

5. Gust-velocity envelopes derived for these operations agree reasonably well with the envelope boundary which represents the range for United States civil transport operations.

6. No clearly defined effects of maneuvers could be discerned in these data.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 20, 1953.

APPENDIX A

DETAILS OF METHOD OF EVALUATION OF RECORDS

The values read from each V-G record were the positive and negative acceleration increments Δn_{max} occurring at speeds above 140 miles per hour, their respective values of airspeed V_o, and the maximum indicated airspeed V_{max}. In addition, the maximum positive and negative Δn values in each 20-mile-per-hour speed bracket covering the range from 140 miles per hour to the highest speed recorded were read from each record. No acceleration increments were read at speeds below 140 miles per hour in order to exclude any maneuvers during take-off and approach and impact shocks during landing. Faulty records and pilot check flight records were not used.

The gust-velocity data presented herein were derived according to the method of reference 6. The maximum positive and negative gust-velocity values were computed for each record by using the acceleration-increment values and their respective values of airspeed V_o in the derived-gust-velocity formula

$$U_{de} = \frac{2W\,\Delta n}{1.47m\rho_o SV_o K_g} \tag{1}$$

The gust factor K_g is a function of the airplane mass ratio μ_g which value is obtained by using the formula

$$\mu_g = \frac{2W}{m\rho\bar{c}gS} \tag{2}$$

The variation of K_g with μ_g is given by the curve shown in figure 2 of reference 6. The value of K_g used for evaluating the gust velocities herein is based on an average operating altitude of 10,000 feet. An examination of time-history records from similar operations has indicated that considerable operating time is spent at altitudes of 10,000 feet where the more turbulent atmospheric conditions were encountered, although on occasion the aircraft may operate to 25,000 feet. Inasmuch as the actual weight was not known at the time of each gust encounter, an average operating weight of 85 percent of gross weight was assumed on the basis of past operations as reasonable for these calculations.

APPENDIX B

DETAILS OF ANALYSIS AND PREPARATION OF TABLES AND FIGURES

Determination of probability distributions.- The V-G records selected for the analysis were restricted to those having record times within the ranges of hours shown in table I, inasmuch as the method of analysis used (see ref. 14) requires reasonably constant record times. The data obtained from those records are listed in table III in the form of frequency distributions of the observed values of Δn_{max}, U_{de}, V_o for Δn_{max}, and V_{max}. Table IV presents the frequency distributions of the observed values of Δn obtained from the 20-mile-per-hour speed brackets of each record.

The statistical-parameter values listed in tables III and IV were calculated from the observed frequencies given in each case for use in obtaining the theoretical probabilities of equaling or exceeding given values of the variable. The parameters of the acceleration and gust-velocity distributions shown in tables III(a), III(b), and IV are: the mean value of the relevant variable $\overline{\Delta n}_{max}$ and $\overline{U}_{de}$, the location parameter u, and the scale parameter α, which were computed by use of the statistical procedures outlined in reference 10. The parameter values for the airspeed distributions shown in tables III(c) and III(d) are: the mean values $\overline{V}_o$ and $\overline{V}_{max}$, the standard deviations σ_o and σ_v, and the coefficients of skewness k_o and k_v, which were obtained by applying the statistical procedures given in reference 11.

By means of these parameters and the method of reference 10, extreme-value distributions were fitted to the Δn_{max}, U_{de}, and Δn distributions by 20-mile-per-hour speed brackets for obtaining values of the probability P of equaling or exceeding given values of the variable. Pearson Type III distributions (see ref. 14) yield reasonable representations of airspeeds and were fitted to the V_{max} distributions of table III(d) to obtain the probability P of equaling or exceeding given values of maximum airspeeds.

A measure of the most probable average operating speed V_p in rough air was computed from the parameters of the V_o distributions by using the relevant equation given in reference 1. The values obtained are given in table III(c).

The theoretical probability distributions obtained for the Δn_{max}, U_{de}, and V_{max} data were transformed to values of average flight miles required to equal or exceed given values of the respective variable by using the formula

$$\text{Flight miles} = 0.8V_C\tau(1/P) \tag{3}$$

where the value $0.8V_C$ is taken as an average operating airspeed based on time-history records obtained on this type of airplane. The curves of average flight miles which were calculated from the theoretical probability distributions of Δn_{max}, U_{de}, and V_{max} are presented in figures 2, 3, and 4, respectively. The cumulative frequencies of the observed data were likewise transformed to values of average flight miles for comparing the measured values with their theoretical probability values.

Composite V-G records and calculation of V-G envelopes.- Although only records with reasonably constant times were analyzed, all the records collected and evaluated (see table I) were used to prepare composite V-G records of each operation. Figures 5 to 7 show these composite records compared with the gust-load envelopes prepared from the records analyzed. The calculated envelope was obtained in each case for a value of flight miles corresponding to that of the composite V-G record. A probability value was obtained for the respective value of flight miles by the use of equation (3). For this probability value the corresponding values of Δn for each 20-mile-per-hour speed bracket (positive and negative values were treated separately) were calculated. These Δn values were plotted at the midpoint speed value of each speed bracket and a curve was faired through these points. In order to complete the envelope from the last speed bracket tabulated to the highest speed flown, the product probability method outlined in reference 2 was used. From envelopes calculated on this basis it is expected that, for the given value of flight miles, an average of one positive and one negative acceleration increment will exceed the envelope in each speed bracket and one maximum airspeed will occur above the maximum speed of the calculated envelope.

Figure 8 shows gust-load envelopes calculated for operations A, B, and C for a distance of 10^7 flight miles compared with a design gust-load diagram obtained according to the Civil Air Regulations of reference 9.

Construction of gust-velocity envelopes.- Figure 9 shows the gust-velocity envelopes calculated for the present operations compared with an envelope boundary prepared by using the data from references 1 to 5 which were reevaluated for obtaining the respective gust-velocity envelopes. The positive and negative gust-velocity values were combined in each of these cases and the envelopes prepared in this manner are symmetrical. Also shown in this figure for comparison is a gust-velocity design diagram which was constructed according to the gust standards of the Convention on International Civil Aviation (see ref. 13) to represent the present type of airplane.

Comparison of loads, gusts, and airspeeds.- The gust loads, gusts, and airspeeds for operations A, B, and C are compared in table II with values from the operations reported in references 2 to 5. The data from these references were reevaluated to obtain equivalent results with those shown for the present airplanes. The most probable speeds at which the largest accelerations occurred are given as a proportion of the cruising speed and are listed as V_p/V_C.

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TABLE I

SCOPE OF V-G DATA FOR OPERATIONS FROM 1949 TO 1953

Operation	Routes flown	Dates of operation	Number of airplanes supplying records	Records collected and evaluated		Records analyzed		Range of record hours analyzed	Average hours per record, τ
				Number	Total hours, T	Number	Total hours, T		
A	New York — Los Angeles — Honolulu	Nov. 1949 to Apr. 1952	5	102	19,676	74	14,953	124 to 311	202
B	Havana — Miami — New York — Detroit	Sept. 1950 to Jan. 1953	4	62	18,413	58	16,546	216 to 383	285
C	Miami — Caribbean — South America	July 1949 to June 1951	2	62	11,566	37	6,602	128 to 330	178

TABLE II

COMPARISON OF LOADS, GUSTS, AND AIRSPEEDS FOR SEVERAL OPERATIONS

[Data from references have been reevaluated to obtain results equivalent to those for the present operations]

Operation	Transport type	Dates of operation	V_p/V_C at Δn_{max}	Average flight miles to exceed -		
				Δn_{LLF} (twice)	$U_{de_{50}}$ (twice)	V_{NE} (once)
Present A	Four-engine	1949 to 1952	0.67	1.4×10^6	0.7×10^6	20.0×10^6
Present B	Four-engine	1950 to 1953	.76	1.0	.5	.5
Present C	Four-engine	1949 to 1951	.75	.9	.4	.2
North-south route central U. S. (ref. 2)	Two-engine	1948 to 1950	.75	2.8	.6	>1000
Northern trans-continental U. S. (ref. 3)	Two-engine	1948 to 1950	.75	1.2	.3	>100
Caribbean-South American (ref. 4)	Four-engine	1947 to 1949	.72	5.6	.9	.1
Eastern U. S. (ref. 5)	Four-engine	1947 to 1950	.83	1.1	.7	3.8

TABLE III

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS

(a) Δn_{max}

Δn_{max}, g units	Number of observations for -								
	Operation A			Operation B			Operation C		
	Total	+	-	Total	+	-	Total	+	-
0.3 to 0.4	5	2	3	--	--	--	--	--	--
.4 to .5	16	6	10	--	--	--	1	0	1
.5 to .6	25	9	16	3	0	3	5	2	3
.6 to .7	33	16	17	8	4	4	2	0	2
.7 to .8	19	10	9	12	7	5	5	1	4
.8 to .9	16	7	9	18	10	8	15	5	10
.9 to 1.0	8	5	3	19	6	13	14	9	5
1.0 to 1.1	13	8	5	15	9	6	15	7	8
1.1 to 1.2	2	1	1	19	10	9	6	5	1
1.2 to 1.3	2	2	0	4	3	1	4	4	0
1.3 to 1.4	2	2	0	8	5	3	4	3	1
1.4 to 1.5	2	2	0	5	2	3	1	1	0
1.5 to 1.6	1	1	0	3	2	1	1	0	1
1.6 to 1.7	1	1	0	1	0	1	1	0	1
1.7 to 1.8	1	0	1	1	0	1	--	--	--
1.8 to 1.9	1	1	0	--	--	--	--	--	--
1.9 to 2.0	0	0	0	--	--	--	--	--	--
2.0 to 2.1	1	1	0	--	--	--	--	--	--
Total, N	148	74	74	116	58	58	74	37	37
$\overline{\Delta n}_{max}$, g units	0.76	0.83	0.69	1.02	1.03	1.01	0.97	1.03	0.91
u	0.63	0.68	0.59	0.90	0.92	0.89	0.87	0.94	0.80
α	4.31	3.75	5.68	5.07	5.18	4.75	5.46	6.25	5.12

TABLE III.- Continued

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS

(b) U_{de}

U_{de}, fps	Number of observations for -								
	Operation A			Operation B			Operation C		
	Total	+	-	Total	+	-	Total	+	-
16 to 20	10	3	7	1	0	1	1	0	1
20 to 24	19	6	13	4	1	3	2	1	1
24 to 28	22	11	11	10	4	6	3	1	2
28 to 32	19	9	10	11	4	7	11	4	7
32 to 36	33	16	17	21	10	11	10	7	3
36 to 40	16	10	6	15	8	7	18	5	13
40 to 44	8	4	4	14	10	4	11	6	5
44 to 48	8	6	2	16	10	6	9	7	2
48 to 52	1	0	1	9	3	6	4	4	0
52 to 56	3	3	0	5	3	2	1	1	0
56 to 60	7	4	3	3	3	0	0	0	0
60 to 64	1	1	0	4	1	3	3	1	2
64 to 68	1	1	0	3	1	2	1	0	1
Total, N	148	74	74	116	58	58	74	37	37
$\overline{U}_{de}$, fps	33.24	35.57	30.92	40.03	41.10	38.96	38.86	40.16	37.57
u	28.53	30.60	26.70	35.23	37.85	33.72	34.70	36.38	33.09
α	0.12	0.12	0.14	0.12	0.14	0.11	0.14	0.15	0.13

TABLE III.- Concluded

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS

(c) V_o for Δn_{max}

Airspeed V_o, mph	Number of observations for - Operation A	B	C
140 to 150	14	--	1
150 to 160	13	1	0
160 to 170	11	1	1
170 to 180	13	6	1
180 to 190	11	14	6
190 to 200	16	17	11
200 to 210	19	15	11
210 to 220	17	5	11
220 to 230	10	12	8
230 to 240	9	11	8
240 to 250	6	6	2
250 to 260	1	8	4
260 to 270	2	6	4
270 to 280	0	4	1
280 to 290	4	4	2
290 to 300	0	1	2
300 to 310	1	4	0
310 to 320	1	1	1
Total, N	148	116	74
$\bar{V}_o$, mph	197.4	223.1	221.1
σ_o	35.90	36.02	32.00
k_o	0.62	0.59	0.67
V_p, mph	186.3	212.5	210.4

(d) V_{max}

Airspeed V_{max}, mph	Number of observations for - Operation A	B	C
280 to 285	2	--	--
285 to 290	3	--	--
290 to 295	5	1	--
295 to 300	4	2	--
300 to 305	12	1	--
305 to 310	17	3	--
310 to 315	8	4	--
315 to 320	9	1	2
320 to 325	4	5	5
325 to 330	3	8	3
330 to 335	4	8	4
335 to 340	2	9	3
340 to 345	1	3	5
345 to 350	--	3	4
350 to 355	--	6	5
355 to 360	--	2	2
360 to 365	--	1	4
365 to 370	--	1	--
Total, N	74	58	37
$\bar{V}_{max}$, mph	309.7	331.7	340.6
σ_v	13.08	16.75	13.70
k_v	0.28	-0.23	-0.02

TABLE IV

FREQUENCY DISTRIBUTIONS OF ACCELERATION INCREMENTS BY AIRSPEED BRACKETS

(a) Operation A

Δn_{max}, g units	Number of observations for airspeed of -																	
	140 to 160 mph		160 to 180 mph		180 to 200 mph		200 to 220 mph		220 to 240 mph		240 to 260 mph		260 to 280 mph		280 to 300 mph		300 to 320 mph	
	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-
0 to 0.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3	3	8	10
.1 to .2	--	--	--	--	1	0	--	--	1	1	3	4	7	12	12	16	17	17
.2 to .3	1	1	1	3	2	4	4	6	6	6	5	11	12	13	22	16	18	20
.3 to .4	17	15	9	10	9	12	7	14	10	14	21	17	20	17	14	19	7	7
.4 to .5	14	16	16	19	10	16	11	11	12	24	13	17	18	18	10	10	2	0
.5 to .6	19	19	7	13	9	15	12	15	11	12	12	13	14	8	6	5	1	0
.6 to .7	16	14	18	13	12	12	10	11	17	11	11	9	1	5	2	3	2	0
.7 to .8	4	3	13	9	11	7	9	6	5	2	6	2	0	1	1	0	0	0
.8 to .9	3	4	2	3	8	5	6	7	4	0	1	0	0	0	0	0	0	1
.9 to 1.0	--	1	4	2	3	2	6	3	3	2	1	0	1	0	0	0	--	--
1.0 to 1.1	--	1	3	1	4	1	4	1	1	2	0	0	0	0	0	0	--	--
1.1 to 1.2	--	--	1	1	0	0	1	0	1	0	0	0	1	0	0	0	--	--
1.2 to 1.3	--	--	--	--	0	0	1	0	2	0	0	0	--	--	0	0	--	--
1.3 to 1.4	--	--	--	--	4	0	0	0	0	0	0	0	--	--	0	0	--	--
1.4 to 1.5	--	--	--	--	1	0	1	0	1	0	0	0	--	--	0	0	--	--
1.5 to 1.6	--	--	--	--	--	--	1	0	--	--	1	0	--	--	0	0	--	--
1.6 to 1.7	--	--	--	--	--	--	1	0	--	--	0	0	--	--	0	0	--	--
1.7 to 1.8	--	--	--	--	--	--	--	--	--	--	0	1	--	--	0	0	--	--
1.8 to 1.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	0	--	--
1.9 to 2.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	0	--	--
2.0 to 2.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	0	--	--
Total, N	74	74	74	74	74	74	74	74	74	74	74	74	74	74	72	72	55	55
$\overline{\Delta n}_{max}$, g units	0.53	0.54	0.62	0.57	0.68	0.55	0.68	0.56	0.59	0.50	0.49	0.45	0.40	0.37	0.36	0.31	0.23	0.21
u	0.46	0.47	0.52	0.48	0.55	0.47	0.55	0.47	0.48	0.42	0.40	0.35	0.33	0.30	0.22	0.23	0.18	0.15
α	9.10	8.00	6.42	6.90	4.55	7.04	4.35	6.41	5.08	7.25	6.06	5.98	7.69	8.40	4.15	8.70	9.26	9.90

TABLE IV.- Continued

FREQUENCY DISTRIBUTIONS OF ACCELERATION INCREMENTS BY AIRSPEED BRACKETS

(b) Operation B

Δn_{max}, g units	Number of observations for airspeed of -																			
	140 to 160 mph		160 to 180 mph		180 to 200 mph		200 to 220 mph		220 to 240 mph		240 to 260 mph		260 to 280 mph		280 to 300 mph		300 to 320 mph		320 to 340 mph	
	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-
0 to 0.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1
.1 to .2	--	--	1	1	--	--	--	--	0	1	--	--	--	--	--	--	1	3	9	14
.2 to .3	2	4	0	1	1	2	0	1	0	0	1	1	--	--	0	1	4	5	13	15
.3 to .4	5	10	0	4	0	1	1	7	0	4	1	4	3	5	3	8	18	16	11	6
.4 to .5	17	17	6	7	2	7	3	3	4	2	4	2	3	7	12	8	11	12	5	3
.5 to .6	17	17	9	10	3	4	4	5	7	9	14	8	13	8	19	12	12	10	2	3
.6 to .7	10	5	14	18	5	10	10	11	13	9	14	16	17	14	14	11	2	5	2	1
.7 to .8	6	2	14	7	13	12	14	11	15	13	15	10	9	9	4	7	1	1	--	--
.8 to .9	1	1	3	4	11	7	9	10	7	6	3	11	9	8	3	8	0	1	--	--
.9 to 1.0	0	2	10	2	10	6	5	3	7	7	2	4	2	3	3	2	3	0	--	--
1.0 to 1.1	--	--	0	3	4	2	6	2	2	2	2	1	0	2	0	0	0	1	--	--
1.1 to 1.2	--	--	0	0	4	5	3	2	2	2	1	1	1	1	0	1	1	0	--	--
1.2 to 1.3	--	--	0	0	2	0	0	0	0	0	1	0	1	1	--	--	0	0	--	--
1.3 to 1.4	--	--	0	1	3	0	0	1	1	1	--	--	--	--	--	--	1	0	--	--
1.4 to 1.5	--	--	1	0	0	1	1	1	0	1	--	--	--	--	--	--	--	--	--	--
1.5 to 1.6	--	--	--	--	0	1	2	0	0	0	--	--	--	--	--	--	--	--	--	--
1.6 to 1.7	--	--	--	--	--	--	0	1	0	0	--	--	--	--	--	--	--	--	--	--
1.7 to 1.8	--	--	--	--	--	--	--	--	0	1	--	--	--	--	--	--	--	--	--	--
Total, N	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	54	54	43	43
$\overline{\Delta n}_{max}$, g units	0.54	0.50	0.71	0.64	0.86	0.76	0.82	0.73	0.75	0.75	0.68	0.69	0.68	0.68	0.59	0.61	0.49	0.45	0.31	0.27
u	0.48	0.43	0.62	0.55	0.76	0.64	0.71	0.61	0.67	0.63	0.60	0.61	0.60	0.59	0.53	0.53	0.39	0.37	0.24	0.21
α	9.90	8.40	6.50	6.06	5.12	4.88	5.18	4.67	6.84	4.67	7.04	7.04	7.40	6.29	8.93	6.76	5.72	7.52	9.26	9.44

TABLE IV.- Concluded

FREQUENCY DISTRIBUTIONS OF ACCELERATION INCREMENTS BY AIRSPEED BRACKETS

(c) Operation C

Δn_{max}, g units	Number of observations for airspeed of -																			
	140 to 160 mph		160 to 180 mph		180 to 200 mph		200 to 220 mph		220 to 240 mph		240 to 260 mph		260 to 280 mph		280 to 300 mph		300 to 320 mph		320 to 340 mph	
	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-
0 to 0.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	1
.1 to .2	1	0	--	--	--	--	--	--	--	--	0	1	1	0	2	0	2	4	7	14
.2 to .3	1	1	--	--	--	--	0	1	0	3	2	1	1	3	1	5	8	8	15	12
.3 to .4	3	5	1	3	0	2	1	1	1	1	0	5	2	3	3	7	6	11	8	7
.4 to .5	10	8	8	8	2	2	1	4	2	4	4	3	5	7	2	7	10	7	2	0
.5 to .6	8	9	10	12	6	5	1	4	2	7	4	5	7	12	13	9	5	4	2	0
.6 to .7	8	8	6	4	7	9	3	5	3	5	6	7	8	4	9	2	1	1	0	0
.7 to .8	4	6	5	7	6	4	9	7	5	8	6	5	7	5	1	5	4	1	0	1
.8 to .9	2	0	4	2	6	7	4	7	6	4	7	5	0	2	3	1	1	1	--	--
.9 to 1.0	--	--	2	1	2	4	6	3	9	4	4	2	3	0	2	0	--	--	--	--
1.0 to 1.1	--	--	1	0	4	1	5	3	7	0	2	3	1	1	0	1	--	--	--	--
1.1 to 1.2	--	--	--	--	2	1	4	0	1	0	1	0	1	0	0	0	--	--	--	--
1.2 to 1.3	--	--	--	--	1	1	3	0	0	0	0	0	0	0	1	0	--	--	--	--
1.3 to 1.4	--	--	--	--	0	1	0	0	1	0	1	0	1	0	--	--	--	--	--	--
1.4 to 1.5	--	--	--	--	1	0	0	0	0	1	--	--	--	--	--	--	--	--	--	--
1.5 to 1.6	--	--	--	--	--	--	0	1	--	--	--	--	--	--	--	--	--	--	--	--
1.6 to 1.7	--	--	--	--	--	--	0	1	--	--	--	--	--	--	--	--	--	--	--	--
Total, N	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	34	35
$\overline{\Delta n}_{max}$, g units	0.55	0.55	0.63	0.59	0.80	0.75	0.89	0.76	0.85	0.67	0.72	0.65	0.65	0.56	0.59	0.51	0.44	0.38	0.28	0.24
u	0.48	0.49	0.56	0.52	0.69	0.65	0.79	0.64	0.77	0.56	0.61	0.54	0.54	0.48	0.50	0.42	0.36	0.31	0.23	0.19
α	8.13	9.26	7.52	8.55	5.50	5.62	5.82	4.53	5.95	5.41	5.26	5.52	5.29	7.25	5.92	6.76	7.14	7.94	12.05	10.64

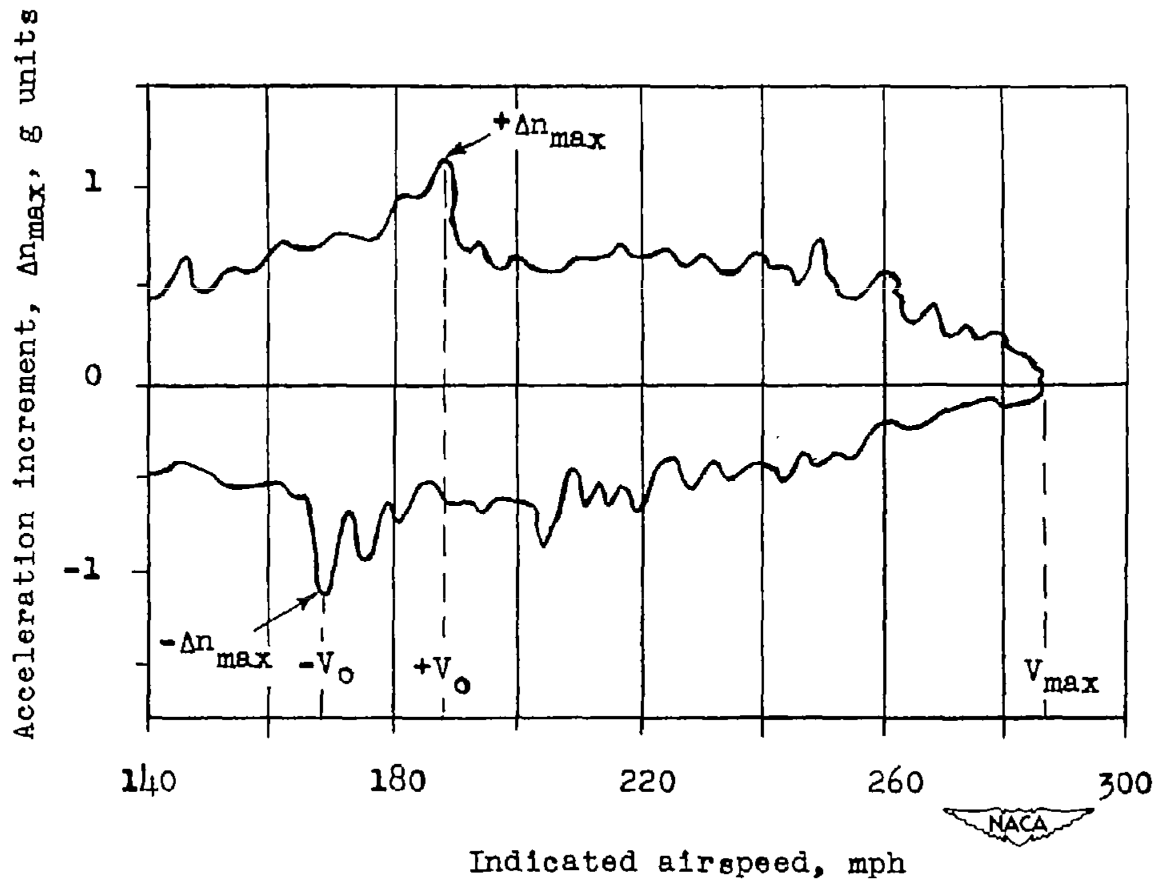

Figure 1.- Evaluated V-G record.

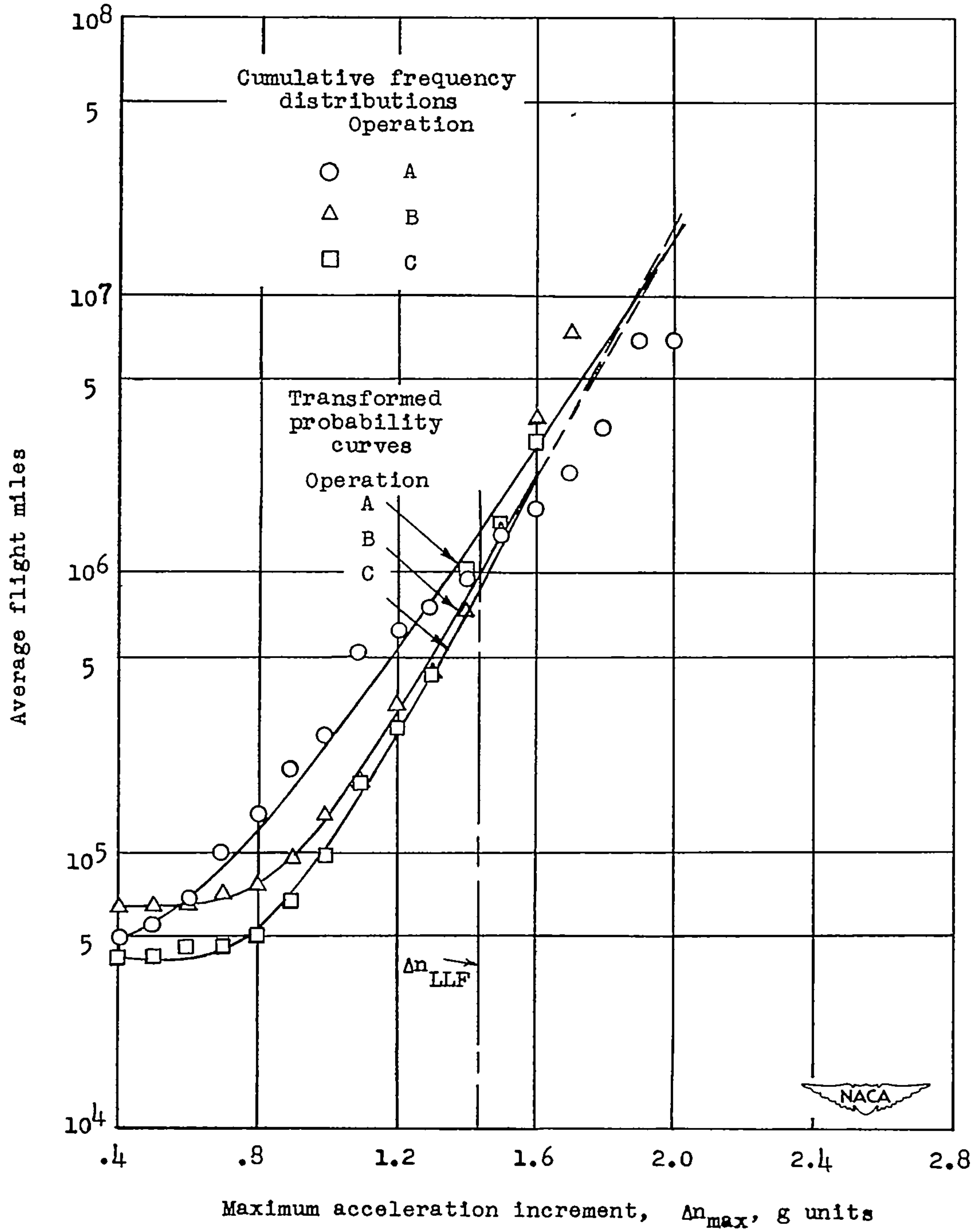

Figure 2.- Average flight miles for a maximum positive and negative acceleration increment to equal or exceed a given value.

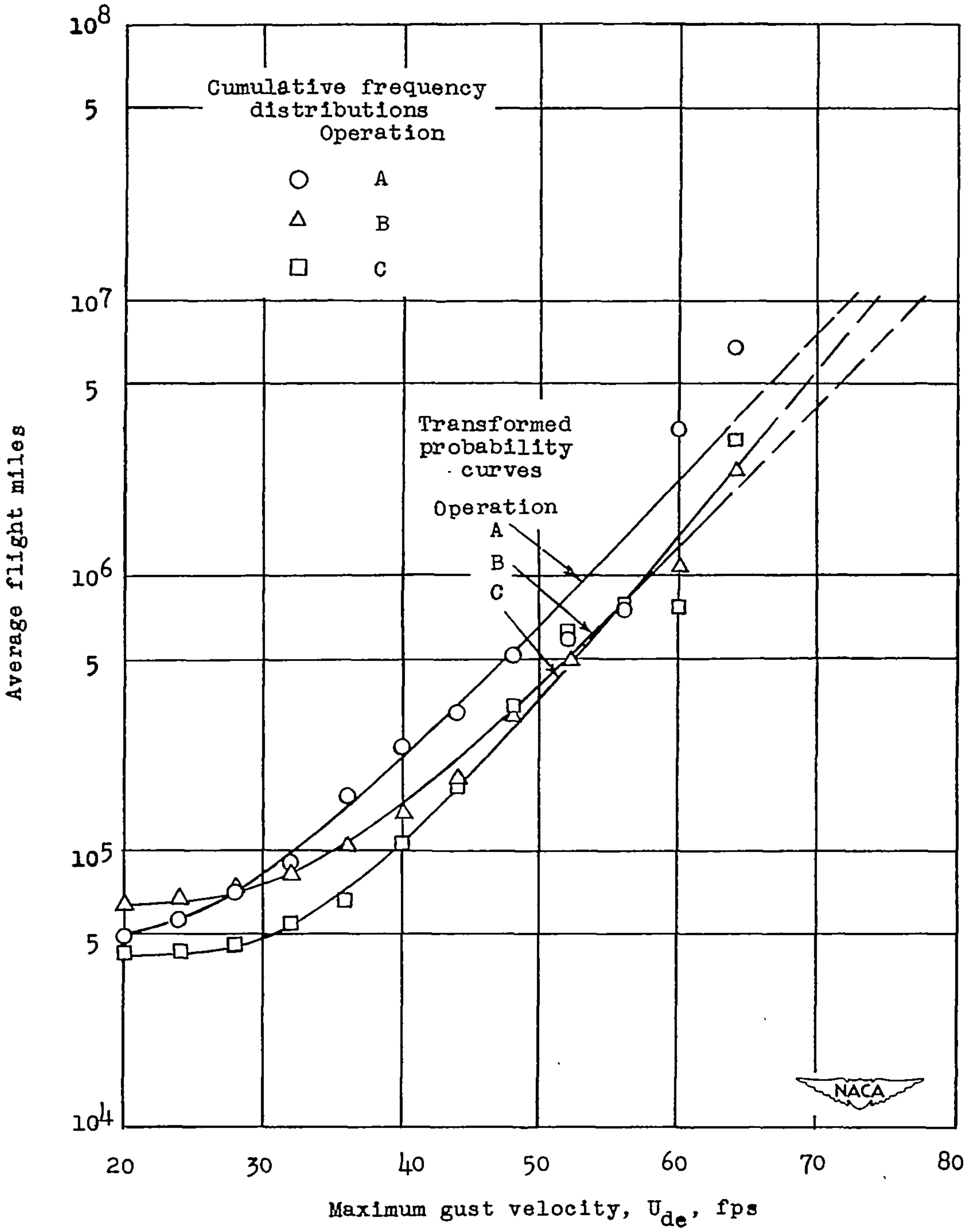

Figure 3.- Average flight miles for a maximum positive and negative gust velocity to equal or exceed a given value.

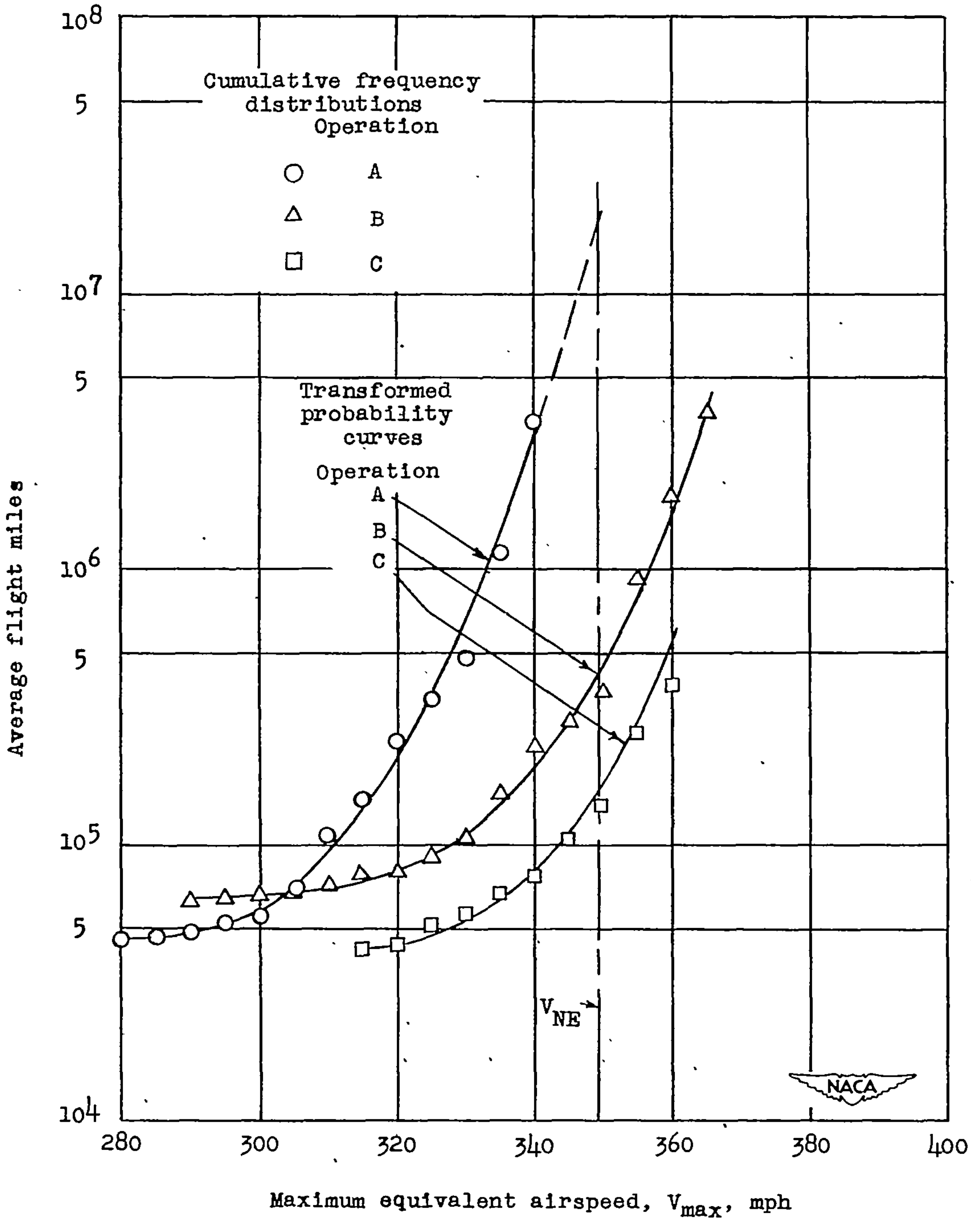

Figure 4.- Average flight miles for maximum equivalent airspeed to equal or exceed a given value.

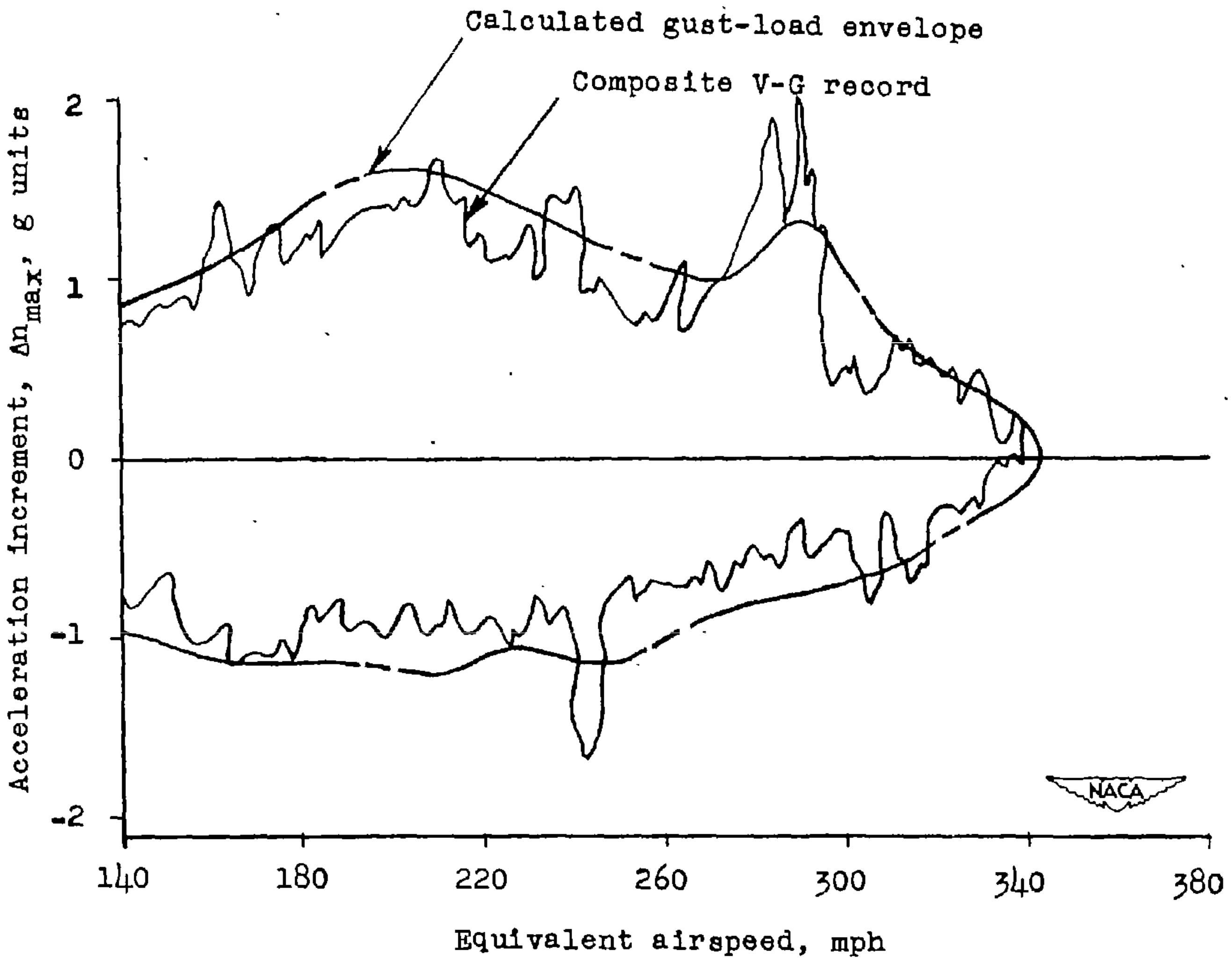

Figure 5.- Comparison of the composite V-G record and a calculated envelope for operation A. Distance represented, 4.4×10^6 flight miles.

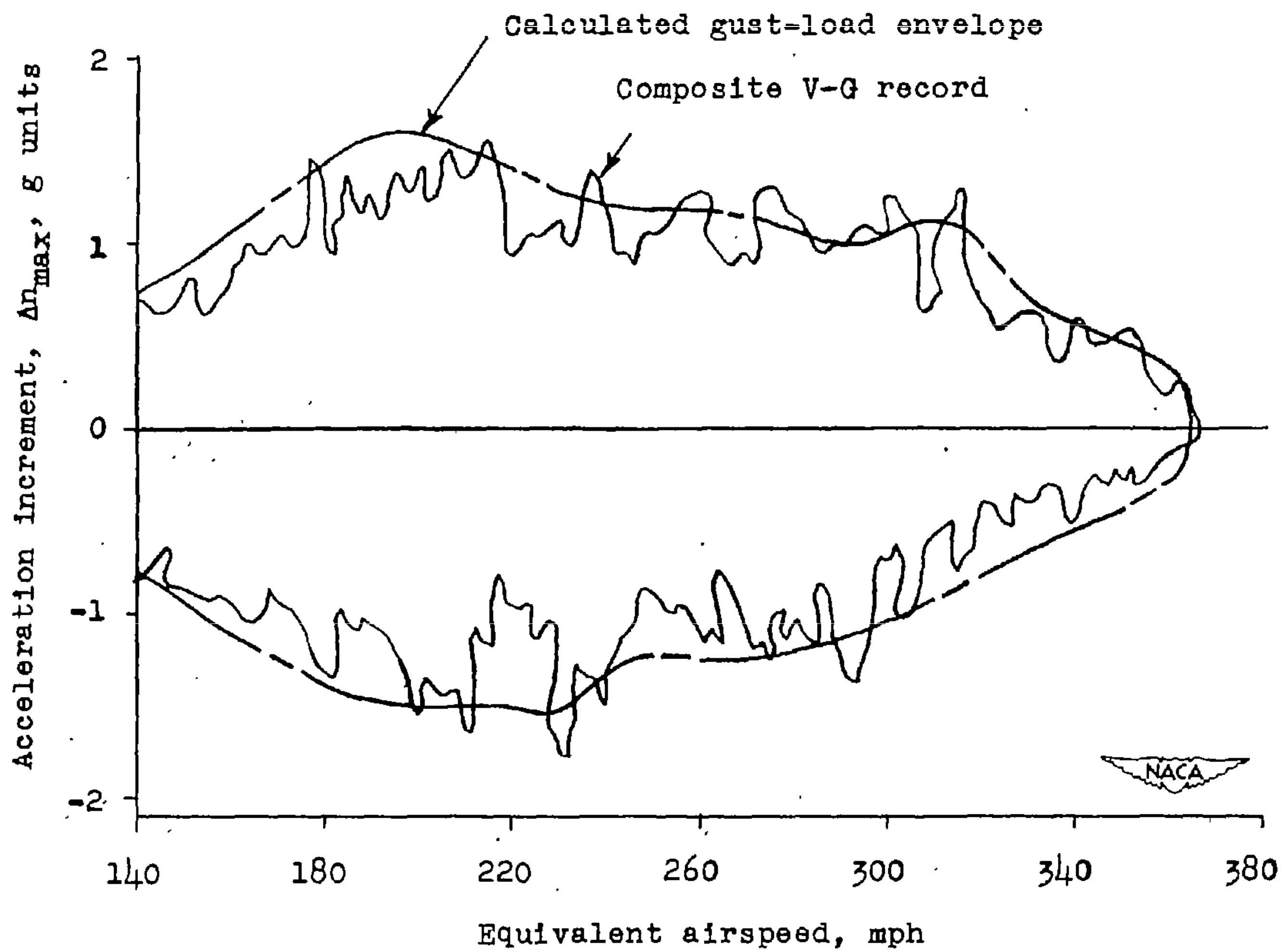

Figure 6.- Comparison of the composite V-G record and a calculated envelope for operation B. Distance represented, 4.1×10^6 flight miles.

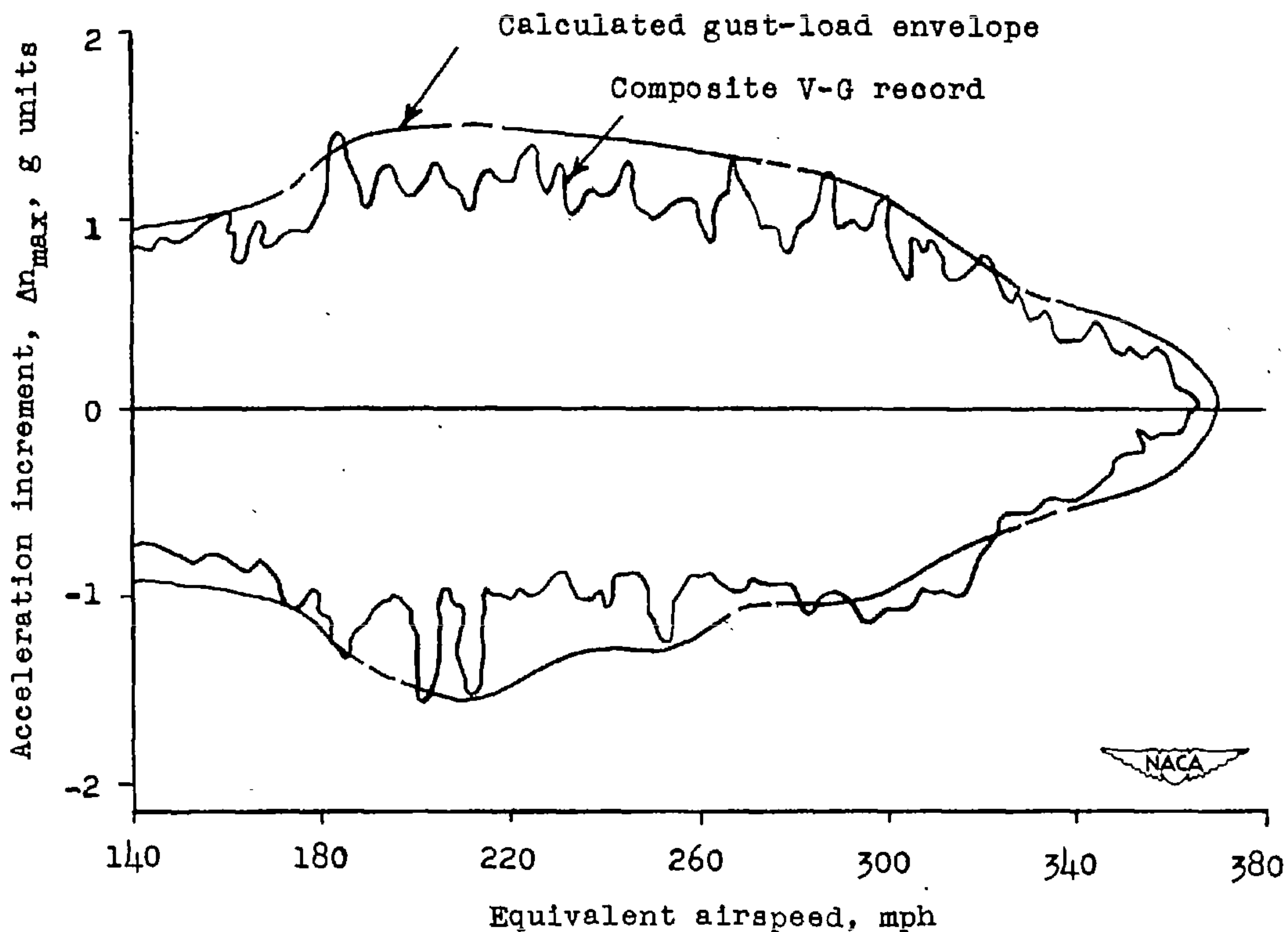

Figure 7.- Comparison of the composite V-G record and a calculated envelope for operation C. Distance represented, 2.6×10^6 flight miles.

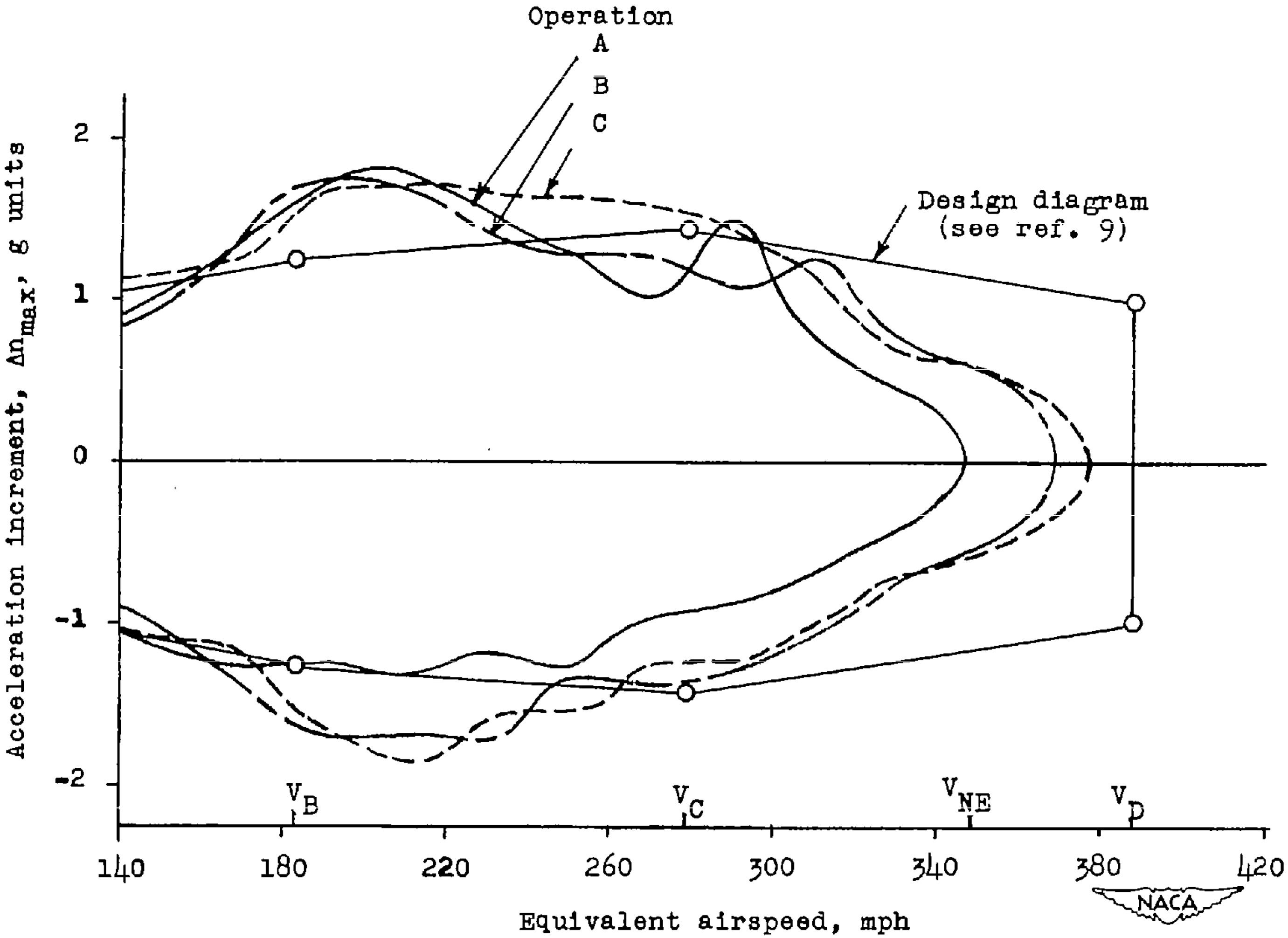

Figure 8.- Comparison of calculated gust-load envelopes for 10^7 flight miles of operations of the four-engine transport airplane on each of three different routes and the design gust-load diagram.

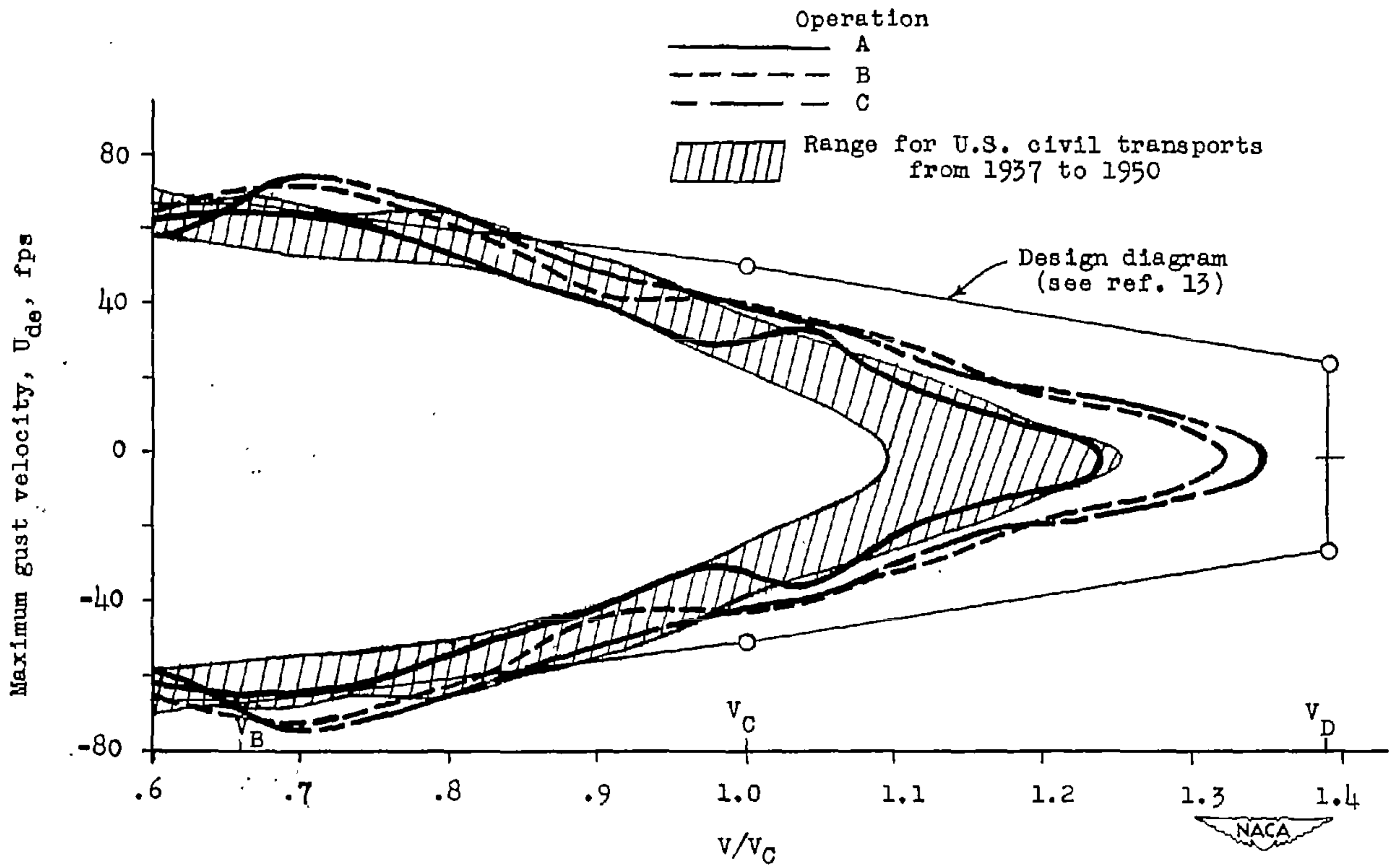

Figure 9.- Comparison of calculated gust-velocity envelopes for 10^7 flight miles of operations of the four-engine transport airplane on each of three different routes and the range for other United States civil-transport operations from references 1 to 5.